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STOIC: an assessment of coupled model climatology and variability in tropical ocean regions

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Introduction

The tropics are regions of strong ocean-atmosphere interaction on seasonal and interannual timescales, so a good representation of observed tropical behaviour is a desirable objective for coupled ocean-atmosphere general circulation models (CGCMs). To broaden and update previous assessments (Mechoso et al. 1995, Neelin et al. 1992), two complementary projects were initiated by the CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP): the El Niño Simulation Intercomparison Project (ENSIP, by Mojib Latif) and STOIC (Study of Tropical Oceans In Coupled models). The aim was to compare models against observations to identify common weaknesses and strengths. Results from ENSIP concentrating on the equatorial Pacific have been described by Latif et al. (2000), hereafter ENSIP2000. A detailed report on STOIC is available via anonymous ftp at `email.meto.gov.uk/pub/cr/ *stoic*` and is summarised in Davey et al. (2000). The STOIC analyses extend beyond the equatorial Pacific, to examine behaviour in all three tropical ocean regions.

The models and observational data

The basic data requested for STOIC were monthly mean fields of tropical SST, surface wind stress, and upper ocean heat content from typical 20 year periods of coupled model integration. Contributions from 21 CGCMs and two simplified-physics models were collected in 1997 and 1998. Note - many of the centres that submitted data will by now be using newer, updated versions of the various models. The models vary considerably in configuration and purpose: see the reports for details. Some have no form of surface 'flux adjustment' (here we use the term liberally to include relaxation to observed SST and anomaly coupling as well as fixed flux alterations), while others have varying degrees of 'adjustment'. For convenience, these two groups are referred to below as 'no-adj' and 'adj' respectively. It is noteworthy, and a mark of the progress made in recent years with coupled models, that the majority used no adjustment.

For comparison monthly gridded datasets based on analyses of observations were obtained from various sources: SST from the Met. Office GISST3 SST/sea-ice dataset; surface windstress from the Southampton Oceanography Centre and from the WM-COADS dataset; and upper ocean heat content from Scripps Institution of Oceanography.

Annual mean climatology

Comparisons between observations and models along zonal (equatorial) and meridional sections were made. With regard to SST, in the Pacific sector an important feature is that the strong east-west SST gradient is by and large correct in all models. However, most of the 'no-adj' models have a systematic cold bias (2C or more in many cases) over much of the equatorial Pacific (see ENSIP2000). In the east Pacific, the observed mean SST rises approaching the South American coast. Most models exaggerate this rise, with positive (and large) SST errors common in this region.

In the Atlantic sector observed mean SST decreases eastward from the American coast, rising again approaching the African coast. However, nearly all the 'no-adj' CGCMs have the opposite SST gradient in the central Atlantic. In these models the SST is biased cold in the west equatorial Atlantic, by up to 3C, but biased warm in the east equatorial Atlantic. (As in the Pacific, the SST rise approaching the east coast is exaggerated, with reduced stratus cloud a likely symptom.) In the equatorial Indian ocean the CGCMs generally have the right zonal gradient, with SST rising rapidly from relatively cold levels at the African coast where upwelling of cold water occurs during the boreal summer season. As in the Pacific, however, most 'no-adj' models have a cold bias.

Annual mean zonal windstress was calculated for a 5N-5S equatorial belt. The results for the 'no-adj' models (Fig. 1, upper panel: see the detailed report for a clearer version) are most varied in the central-west Pacific sector, where all models (with the exception of CERFACS) differ substantially from the observations. In the central Pacific (180E to 240E) the easterly windstresses are underestimated by many models, whereas in the west Pacific (west of 160E) the windstress is strongly easterly in most models, instead of near zero as observed. The substantial windstress gradient (increasing easterlies from 130E to 200E) is missed by all but CERFACS. The model biases are much larger than the difference between the SOC and WM-COADS observations. By contrast, the model windstresses are close to the observations in the east equatorial Pacific (east of 100W).

In general, the 'no-adj' models have both too-cool SST and too-weak easterly windstress in the central equatorial Pacific. The 'obvious' cold bias explanation (equatorial SST too cold because local easterlies and upwelling too strong) does not seem to apply.

In the equatorial Atlantic the 'no-adj' wind stresses are nearly all much weaker than observed: only COLA has the right strength. However the zonal gradients are quite similar to that observed, which at first sight is surprising in view of the poor zonal SST gradients. Further investigation is needed to explain this contrast in wind stress and SST gradient performance. Part of the explanation may be that the equatorial windstresses are controlled more by off-equatorial factors (e.g. SST distribution, and the location and strength of convection centres) in the Atlantic. The weakened easterlies may be connected with shifts in the main convection centres in the east Atlantic that are associated with warm SST biases in that region. Wind stress results for the 'adj' CGCMs (Fig. 1, lower panel) show distributions quite similar to that observed in the Pacific and Atlantic sectors, but with substantial differences in strength. In the equatorial Atlantic several models substantially underestimate the magnitude of the easterlies. In the Indian sector several 'adj' and 'no-adj' models seriously underestimate the westerly windstress in the central Indian ocean, and some have mean easterlies in this area.

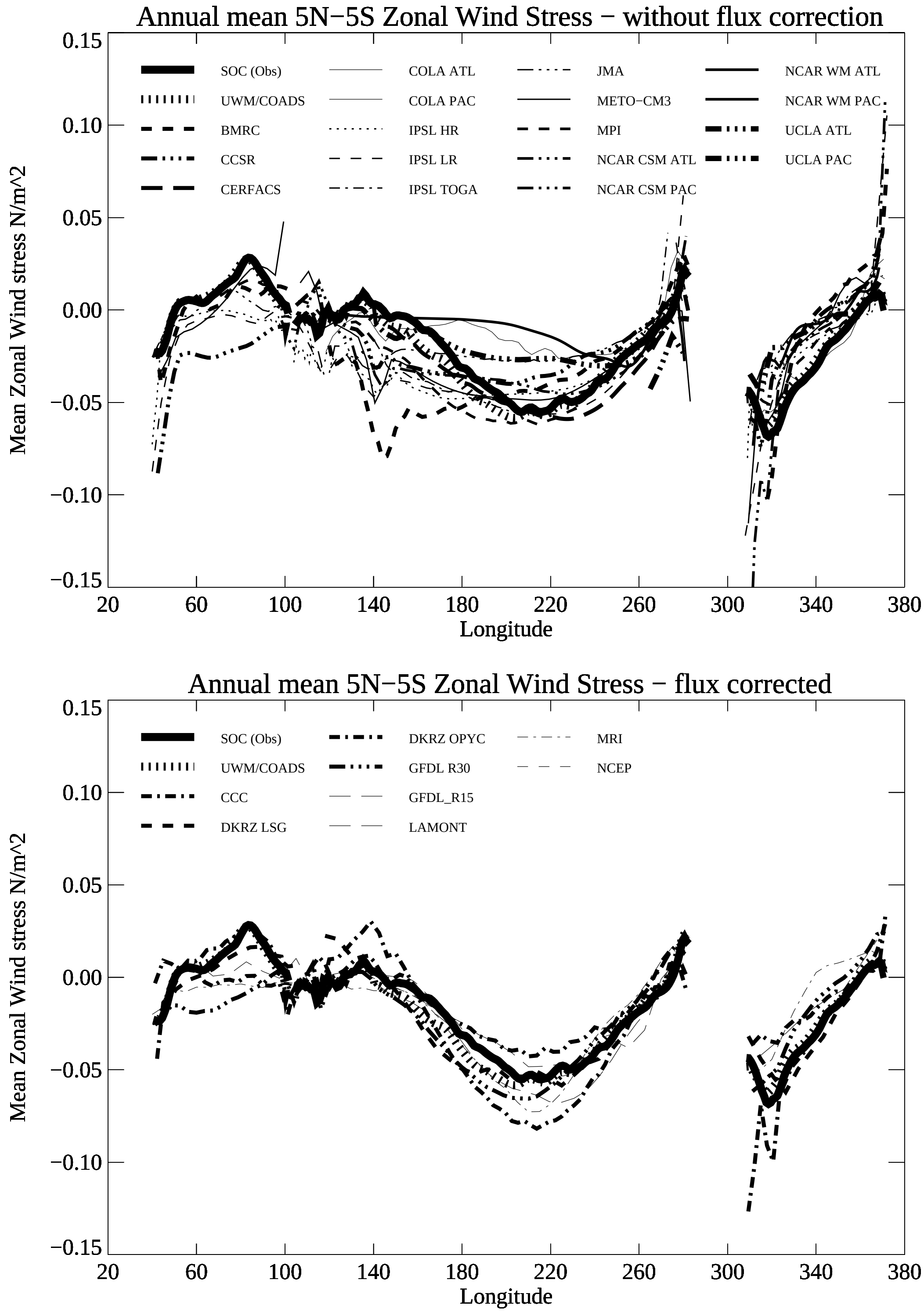

Fig. 1: Annual mean zonal windstress zonal section in the equatorial strip 5N-5S, as observed and for (upper panel) 'no-adj' models, (lower) 'adj' models.

Interannual variability

Interannual variability was assessed in various ways: see ENSIP2000 and the STOIC report for details. Standard deviations, SST correlations, and wind stress composites were calculated. In the tropical Pacific interannual variability levels in most models were lower than observed. This was particularly evident for wind stress: for example, none of the CGCMs had zonal wind stress standard deviations matching observed levels in the central-east equatorial Pacific. In the Atlantic and Indian sectors, which are less active than the Pacific, several CGCMs were able to match the observed levels, but others generally erred on the low side. Most models were not able to reproduce the observed lag relation between Indian and Pacific ocean SST anomalies.

Wind stress anomaly patterns composited on Niño3 SST variability above and below 1 standard deviation showed that most models were able to capture the main observed features (for positive SST': westerly anomalies in the central equatorial Pacific with flanking convergent equatorward motion; westerly anomalies in the north and south mid-latitude Pacific; converging northerly and southerly anomalies in the east equatorial Pacific; easterly anomalies in the east equatorial Indian ocean; easterly anomalies in the tropical north Atlantic), at least in terms of sign if not magnitude, even though the variability in most of the models was not realistically ENSO-like.

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